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Applicant(s)	:	Leyden et al.
Appl. No.	:	To be assigned
Filed	:	November 21, 2003
Title	:	Selective Deposition Modeling Method and Apparatus for Forming Three-Dimensional Objects and Supports
Grp./A.U.	:	To be assigned
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Docket No.	:	USA.208-4
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Date of Deposit
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MS PATENT APPLICATION
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PRELIMINARY AMENDMENT

Dear Sir:

This Preliminary Amendment is filed concurrently with the filing of the above-identified continuation application for Letters Patent. Please make the following changes:

In the Specification:

Paragraph beginning at line 4 of page 1 has been amended as follows:

This application is a continuation of U.S. Application Serial No. 09/924, 608, filed August 6, 2001, which is a continuation of prior U.S. Application Serial No. 09/252,512, filed February 18, 1999, now U.S. Patent 6,270,335, issued August 7, 2001; which is a divisional of U.S. Application Serial No. 08/722,335, filed September 27, 1996, now abandoned, which ~~This application~~ is a continuation-in part of U.S. Application Serial No. 08/534,813, filed September 27, 1995, now abandoned.--

Page 7, in the table between lines 5 and 10:

Filing Date	Application No.	Title	Status
9/27/95	08/534,813	Selective Deposition Modeling Method and Apparatus for Forming Three-dimensional Objects and Supports	Abandoned ~~Pending~~
9/27/95	08/534,447	Method and Apparatus for Data Manipulation and System Control in a Selective Deposition Modeling System	Abandoned ~~Pending~~
9/27/95	08/535,772	Selective Deposition Modeling Materials and Method	Abandoned ~~Pending~~
9/27/95	08/534,477	Selective Deposition Modeling Method and System	Abandoned ~~Pending~~

Page 7, in the table between lines 16 and 17:

~~Docket No.~~	Filing Date	Application No.	Title	Status
~~USA.143~~	9/27/96 ~~Concurrently herewith~~	08/722,326 ~~Not yet assigned~~	Method and Apparatus for Data Manipulation and System Control in a Selective Deposition Modeling System	Issued U.S. Patent No. 5,943,235 ~~Pending~~

Paragraph beginning at line 14 of page 8 has been amended as follows:

U.S. Patent Application No. 08/534,447, now abandoned, referenced above, is directed to data transformation techniques for use in converting 3D object data into support and object data for use in a preferred Selective Deposition Modeling (SDM) system based on SDM/TSL principles. This referenced application is also directed to various data handling, data control, and system control techniques for controlling the preferred SDM/TSL system described hereinafter. Some alternative data manipulation techniques and control techniques are also described for use in SDM systems as well as for use in other RP&M systems.

Paragraph beginning at line 21 of page 8 has been amended as follows:

U.S. Patent Application No. 08/535,772, now abandoned, as referenced above, is directed to the preferred material used by the preferred SDM/TSL system described herein. Some alternative materials and methods are also described.

Paragraph beginning at line 24 of page 8 has been amended as follows:

U.S. Patent Application No. 08/534,477, now abandoned, as referenced above, is directed to some particulars of the preferred SDM/TSL system. Some alternative configurations are also addressed.

Pages 9-10, in the table:

App No. Filing Date	Topic	Status and/or Patent No.
08/484,582 Jun 7, 1995	Fundamental elements of Stereolithography are taught.	5,573,722 ~~Pending~~
08/475,715 Jun 7, 1995	Various recoating techniques for use in SL are described including a material dispenser that allows for selective deposition from a plurality of orifices.	5,667,820 ~~Pending~~
08/479,875 Jun 7, 1995	Various LOM type building techniques are described.	5,637,169 ~~Pending~~
08/486,098 Jun 7, 1995	A description of curl distortion is provided along with various techniques for reducing this distortion.	Abandoned ~~Pending~~
08/475,730 Jun 7, 1995	A description of a 3D data slicing technique for obtaining cross-sectional data is described which utilizes Boolean ~~boolean~~ layer comparisons to define down-facing, up-facing and continuing regions. Techniques for performing cure-width compensation and for producing various object configurations relative to an initial CAD design are also described.	5,854,748 ~~Pending~~
08/480,670 Jun 7, 1995	A description of an early SL Slicing technique is described including vector generation and cure width compensation.	5,870,307 ~~Pending~~
08/428,950 Apr 25, 1995	Various building techniques for use in SL are described including various build styles involving alternate sequencing, vector interlacing and vector offsetting for forming semi-solid and solid objects.	Abandoned ~~Pending~~

08/428,951 Apr 25, 1995	Simultaneously Multiple Layer Curing techniques for SL are taught including techniques for performing vertical comparisons, correcting errors due to over curing in the z-direction, techniques for performing horizontal comparisons, and horizontal erosion routines.	5,999,184 ~~Pending~~
08/405,812 Mar 16, 1995	SL recoating techniques using vibrational energy are described.	5,688,464 ~~Pending~~
08/402,553 Mar 13, 1995	SL recoating techniques using a doctor blade and liquid level control techniques are described.	5,651,934 ~~Pending~~
08/382,268 Feb 1, 1995	Several SL recoating techniques are described including techniques involving the use of ink jets to selectively dispense material for forming a next layer of unsolidified material.	Abandoned ~~Pending~~
08/148,544 Nov 8, 1993	Fundamental elements of thermal stereolithography are described.	5,501,824
07/182,801 Apr 18, 1988	Support structures for SL are described.	4,999,143
07/183,015 Apr 18, 1988	Placement of holes in objects for reducing stress ~~in SL objects~~ are described.	5,015,424
07/365,444 Jun 12, 1989	Integrated SL building, cleaning and post curing techniques are described.	5,143,663
07/824,819 Jan 22, 1992	Various aspects of a large SL apparatus are described.	5,182,715
07/605,979 Oct 30, 1990	Techniques for enhancing surface finish of SL objects are described including the use of thin fill layers in combination with thicker structural layers and meniscus smoothing.	5,209,878
07/929,463 Aug 13, 1991	Powder coating techniques are described for enhancing surface finish.	5,234,636
07/939,549 Aug 31, 1992	Building techniques for reducing curl distortion in SL (by balancing regions of stress and shrinkage) are described.	5,238,639

Paragraph beginning at line 5 of page 12 has been amended as follows:

A seventh object of the invention is to provide ~~is to a provide~~ a method and apparatus that forms a support structure that is easily removed from down-facing surfaces of the object.

Paragraph beginning at line 16 of page 13 has been amended as follows:

Figures 10a and 10b illustrate two ~~illustrates two~~ examples of deposition propagation in the main scanning direction:

Paragraph beginning at line 7 of page 14 has been amended as follows:

Figures 24a-d illustrate a ~~illustrates a~~ deposition embodiment that reduces risk of bridging between regions separated by a gap;

Paragraph beginning at line 9 of page 14 has been amended as follows:

Figures 25a-e illustrate a ~~illustrates a~~ building technique wherein the object is separated into pieces, built separately and then adhered together.

Paragraph beginning at line 25 of page 14 has been amended as follows:

As previously discussed, the subject application is directed to support techniques and building techniques appropriate for use in a Selective Deposition Modeling (SDM) system. In particular, the preferred SDM system is a Thermal Stereolithography (TSL) system. The Description Of The Preferred Embodiments will begin with a description of the preferred TSL system. A more detailed description of the preferred system, data manipulation techniques, system control techniques, material formulations and properties, and various alternatives are described in previously referenced and incorporated U.S. Patent Application Nos. 08/534,813; 08/534,447, now abandoned; 08/535,772; and 08/534,477, now abandoned; and U.S. Pat. No. 5,943,235 ~~3D Docket Nos. USA.143~~, filed concurrently herewith. Further alternative systems are discussed in a number of the previously incorporated applications and patents, especially those referenced as being directly related to, or applicable to, SDM, TSL or Fused Deposition Modeling (FDM). As such, the support structures and build styles described hereinafter should be construed as applicable to a variety of SDM, TSL and FDM systems and not limited by the system examples described herein. Furthermore, as noted previously, these support structures and build styles have utility in the other RP&M technologies.

Paragraph beginning at line 20 of page 15 has been amended as follows:

Furthermore, at either side of the platform 18, fans (not shown) are mounted for blowing air vertically downward to help cool the dispensed material 14 and part-building platform 15 such that the desired building temperature is maintained. Other suitable mounting schemes for the fans and/or other cooling systems include, but are not limited to, misting devices for directing vaporizable liquids (e.g. water, alcohol, or solvents) onto the surface of the object, forced air cooling devices with fans mounted between the planarizer 11 and the dispensing head 9, and forced air cooling devices with stationary or moving fans mounted off the dispensing platform. Cooling systems may include active or passive techniques for removing heat which may be computer controlled in combination with temperature sensing devices to maintain the previously

dispensed material within the desired building temperature range. Other approaches to cooling include, but are not limited to, salting the material with a substance which functions as a black body radiator, especially at IR frequencies, such that heat is more readily radiated from the object during the building process. Further alternative approaches include, but are not limited to, adding a conductive substance to the material every few layers, adding a solvent to the material, building parts with cooling passages or with an embedded substrate (such as interlaced wires) for cooling, or building on a glass plate or Mylar® sheet ~~mylar sheet~~.

Paragraph beginning at line 23 of page 16 has been amended as follows:

The print head 9 is a commercial print head configured for jetting hot melt inks such as, for example, thermal plastics or wax-like materials, and modified for use in a three-dimensional modeling system, wherein the print head undergoes back and forth movements and accelerations. The print head modifications include configuring any on board reservoir such that the accelerations result in minimal misplacement of material in the reservoir. One preferred embodiment includes a 96 jet commercial print head, Model No. HDS 96i, sold by Spectra Corporation, Nashua, Hew Hampshire including reservoir modifications. The print head is supplied material in a flowable state from a Material Packaging & Handling Subsystem (not shown), which is described in the previously referenced U.S. Patent Application No. 08/534,477, now abandoned. In the preferred embodiment, all 96 jets on the head are computer controlled to selectively fire droplets through orifice plate 10 when each orifice (i.e. jet) is appropriately located to dispense droplets onto desired locations. In practice, approximately 12,000 to 16,000 commands per second have been sent to each jet selectively commanding each one to fire (dispense a droplet) or not to fire (not to dispense a droplet) depending on jet position and desired locations for material deposition. Also, in practice, firing commands have been sent simultaneously to all jets. Since, the preferred print head mentioned above contains almost 100 jets, the above noted firing rates result in the need to send approximately 1.2 to 1.6 million firing commands to the head each second. Thus, the head is computer controlled so as to selectively fire the jets and cause them to simultaneously emit droplets of the molten material through one or more orifices in orifice plate 10. Of course, it will be appreciated that in alternative preferred embodiments, heads with different numbers of jets can be used, different firing frequencies are possible, and in appropriate circumstances non-simultaneous firing of the jets is possible.

Paragraph beginning at line 16 of page 17 has been amended as follows:

To most effectively build a three-dimensional object, it is desired that all of the jets fire ~~jets first~~ correctly. To ensure that all jets are firing correctly or at least maximize the number which are firing correctly, various techniques can be used. One such embodiment involves checking the jets after formation of each lamina. This technique includes the steps of: 1) forming a lamina; 2) checking the jets by printing a test pattern of lines on a piece of paper, with all jets firing; 3) optically detecting (through bar code scanning or the like) whether a jet is misfiring; 4) unclogging the jet; 5) removing the entirety of the just-dispensed layer (e.g. by machining using a preferred planarizer to be described herein after); and 6) rebuilding the layer with all jets including the unclogged jet.

Paragraph beginning at line 15 of page 18 has been amended as follows:

The orifice plate 10 is mounted on the dispensing platform 18 such that droplets of material are allowed to emit from the underside of the dispensing platform 18. The orifice plate 10 is illustrated in Figures 4a and 4b. In one preferred embodiment, and as depicted in Figure 4a, the orifice plate 10 (i.e. the line of orifices) is mounted approximately perpendicular to the main scanning direction (X-direction) and is configured with N = 96 individually controllable orifices (labeled 10(1), 10(2), 10(3) . . . 10(96)). Each ~~10(96))Each~~ orifice is equipped with a piezoelectric element that causes a pressure wave to propagate through the material when an electric firing pulse is applied to the element. The pressure wave causes a drop of material to be emitted from the orifice. The 96 orifices are controlled by the control computer which controls the rate and timing of the firing pulses applied to the individual orifices. With reference to Figure 4a, the distance "d" between adjacent orifices in the preferred embodiment is about 8/300 of an inch (about 26.67 mils or 0.677 mm). Thus, with 96 orifices, the effective length "D" of the orifice plate is about (N x 8/300 inch) = (96 x 8/300 inches) = 2.56 inches (65.02 mm).

Paragraph beginning at line 14 of page 23 has been amended as follows:

With reference to Figure 3 ~~Figure 3a~~, part-building platform 15 is also provided. The three-dimensional object or part, identified in the figure with reference numeral 14, is built on the platform 15. The platform 15 is slidably coupled to Y-stage 16a and 16b which controllably moves the platform back and forth in the Y-direction (i.e., index direction or secondary scanning direction) under computer control. The platform 15 is also coupled to Z-stage 17 which

controllably moves the platform up and down (typically progressively downward during the build process) in the Z-direction under computer control.

Paragraph beginning at line 14 of page 25 has been amended as follows:

Further, the dispensing head, in tracing a given scan line, may only maintain a substantially constant velocity over part of the scan line. During the remainder of the scan, the head 9 will either be accelerating or decelerating. Depending on how the firing of the jets is controlled this may or may not cause a problem with excess build up during the acceleration and deceleration phases of the motion. In the event that velocity changes can cause problem in a accumulation rate, the part or support building can be confined to the portion of the scan line over which the print head has a substantially constant velocity. Alternatively, as discussed in the concurrently filed U.S. Patent Application 08/722,326, now U.S. Patent No. 5,943,235 ~~corresponding to 3D Docket No. USA.143~~, a firing control scheme can be used which allows accurate deposition during the acceleration or deceleration portions of a scan line.--

Paragraph beginning at line 29 of page 30 has been amended as follows:

To build a cross-section, the bit map is first loaded with data representative of the desired cross-section (as well as any supports which are desired to be built). Assuming, as with some preferred embodiments, a single build and support material is being used. If it is desired to deposit material at a given pixel location, then the memory cell corresponding to that location is appropriately flagged (e.g. loaded with a binary "1") and if no material is to be deposited an opposite flag is used (e.g. a binary "0"). If multiple materials are used, cells corresponding to deposition sites are flagged appropriately to indicate not only drop location sites but also the material type to be deposited. For ease of data handling, compressed data defining an object or support region (e.g. RLE data which defines on-off location points along each raster line as described in concurrently filed U.S. Patent Application No. ~~___,___ corresponding to 3D Systems' Docket No. USA.143~~)] 08/722,326, now U.S. Patent No. 5,943,235 can be Booleaned ~~booleaned~~ with a fill pattern description (e.g. Style file information as described in U.S. Patent No. 5,943,235 ~~Docket USA.143~~) to be used for the particular region to derive a final bit map representation used for firing the dispensing jets. The actual control of the jets may be governed by a subsequently modified bit map which contains data which has been skewed or otherwise modified to allow more efficient data passing to the firing control system. These considerations

are discussed further in the U.S. Patent Application based on 3D Systems' U.S. Patent No. 5,943,235 ~~Docket Number USA.143~~. The raster lines making up the grid are then assigned to individual orifices in the manner described earlier. Then, a particular orifice is directed to fire or not at firing locations corresponding to desired drop locations or pixel locations depending on how the corresponding cells in the bit map are flagged.--

Paragraph beginning at line 20 of page 31 has been amended as follows:

As discussed above, the print head 9 is capable of depositing droplets at many different resolutions. In some preferred embodiments of the present invention SDP = SDL = 300 pixels and drops per inch. Also in some preferred embodiments, MDL is allowed ~~MD L is allowed~~ to take on three different values while MDP remains fixed 1) MDL = 300 drops per inch and MDP = 300 pixels per inch; 2) MDL = 600 drops per inch; and MDP = 300 pixels per inch or 3) MDL = 1200 drops per inch and MDP = 300 pixels per inch. When the MDL to MDP ratio is greater than one, the extra drops per pixel are made to occur at intermediate locations (ID overprinting) between the centers of the pixels. With the currently preferred print head and material, the volume per drop is about 80 to 100 picoliters which yields roughly drops having a 2 mil (50.8 μm) diameter. With the currently preferred print head, the maximum frequency of firing is about 20 kHz ~~20 Khz~~. By way of comparison, a firing rate of 1200 dpi at 13 ips involves a firing frequency of about 16 kHz ~~16 Khz~~, which is within the permissible limit.

Paragraph beginning at line 22 of page 34 has been amended as follows:

Figures 27a-27e illustrate the relationships between firing location, drop location, and time of flight wherein like elements are referenced with like numerals. Figure 27a illustrates the situation where firing locations 404a and 404b are both coincident with desired drop location 402 (i.e. no time of flight correction factor is used). Element 404a represents the firing location when the head is passing in the positive X-direction, represented by element 406a, and element 404b represents the firing location when the head is passing in the negative X-direction, represented by element 406b. Elements 408a and 408b represent the nominal path followed by the droplets after leaving firing locations 404a and 404b, respectively. The nominal paths 408a and 408b direct the droplets to actual drop locations 410a and 410b, where the droplets impact the surface and form impacted droplets 412a and 412b. The crossover ~~cross-over~~ point (i.e. focal point) for the

droplets fired, while scanning in both directions, is depicted with numeral 414. The plane defined by the crossover ~~cross-over~~ points for the entire layer may be called the focal plane. Elements 416a and 416b represent the time of flight factor used in terms of an X-displacement between the firing locations and the desired drop location. Whether or not the actual drop locations match the desired drop location determines the appropriateness of the correction ~~the correction~~ factor. In Figure 27a it can be seen that the droplets are moving in diverging directions and that the impacted droplets do not overlap at the working surface resulting in a minimal build up in Z and inaccurate XY placement of material. Figure 27b represents the situation where a small time of flight correction factors 416a and 416b are used which result in a focal point located above the desired working surface and in a closer spacing of the impacted droplets 412a and 412b as compared to that depicted in Figure 27a. If the time of flight correction were any larger, Z build up would be increased due to the overlap or superposition of impacted droplets 412a and 412b. Figure 27c represents a situation where the time of flight correction factors used result in the most accurate placement of impacted droplets 412a and 412b (assuming the thickness of impacted droplet 412a is small compared to the drop distance 418 and that the angle of incidence is not too large). If optimal time of flight correction is based on maximum Z accumulation, then ~~accumulation then~~ Figure 27c depicts the optimal situation. Figure 27d represents the situation where the time of flight correction factors 416a and 416b are slightly larger than those used in Figure 27c but still result in Z-accumulation based on the superposition of both droplets. The X-direction placements of the droplets are still reasonably accurate and the focal point 414 of dispensing is somewhat below the desired working surface (and actual working surface). Figure 27e represents the situation where even larger time of flight correction factors are used such that Z-accumulation is reduced to a minimal amount and where the focal point is even further below the desired working surface.

Paragraph beginning at line 17 of page 36 has been amended as follows:

In other preferred embodiments the optimal time of flight correction factor is not set at a value which yields the most accurate targeting (i.e. the focal point is not at the working surface) but instead is set at a value ~~a value~~ which would yield most accurate targeting some distance below the actual working surface (i.e. the focal point is located below the working surface). These embodiments may be called "off surface targeting" embodiments. In this context, most accurate targeting is considered to occur when vertical accumulation rate is the greatest and

probably when the X position is most precisely impacted. Figure 27d depicts an example of targeting for these off surface targeting embodiments. These off surface targeting embodiments are believed to be particularly useful when building is to occur without the use of additional components for maintaining the desired and actual working surface at the same level (e.g. without a planarizer or without additional elements such as a surface level detection device and adjustment mechanisms or schemes).

Paragraph beginning at line 29 of page 36 has been amended as follows:

A characteristic of these off surface targeting embodiments is that Z-accumulation is self-correcting or self-compensating ~~self compensating~~. As long as the Z-increments between deposition of successive layers are within an appropriate range and the deposition pattern allows horizontal spreading of dispensed material instead of only vertical accumulation, excess Z-accumulation on one layer causes a reduction in Z-accumulation on one or more subsequent layers causing the net accumulation to maintain the focal point somewhat below the actual working surface. On the other hand, again as long as Z-increments between deposition of successive layers is within an appropriate range and the deposition pattern allows horizontal spreading of dispensed material instead of only vertical accumulation, too little Z-accumulation on one layer causes an increase in Z-accumulation on one or more subsequent layers thereby causing net accumulation to maintain the focal point somewhat below the actual working surface. The preferred Z-increment range is discussed further below.

Paragraph beginning at line 11 of page 37 has been amended as follows:

This self-correcting ~~self correcting~~ aspect can be understood by studying and comparing Figures 27c, 27d and 27e. When deposition begins (e.g. at the platform) the time of flight correction factor(s) are chosen such that the focal point is somewhat below the actual working surface as depicted in Figure 27d (i.e. the focal point should be set at an appropriate position such that the situations depicted in Figures 27c and 27e do not occur). If when forming the first layer, too little material is deposited, for the given Z-increment being used, the actual surface will be lower as compared to the repositioned focal plane (but will still be above it as long as the Z-increment was not too large). This results in a more optimally focused deposition when forming the next layer, this in turn results in an increase in deposition thickness as depicted in Figure 27c. If the net Z-accumulation resulting from depositing the second layer is still too low (as compared

to the two Z-increments made), then the next layer when being deposited will have an actual surface which is closer ~~which closer~~ to the optimal focus plane than the original surface was. This closer approach to optimal positioning results in increased Z-accumulation which will again drive the net accumulated thickness toward that required by the Z-increments. On the other hand, if net accumulation from depositing the second layer is greater than that dictated by the two Z-increments, then the actual working surface will be further away from the focal plane and less Z-accumulation, upon forming the next layer, will occur thereby driving the net accumulation toward the amount required by the Z-increments. This is the situation depicted in Figure 27e.

Paragraph beginning at line 11 of page 38 has been amended as follows:

As noted above, in some of these embodiments objects may be formed in such a manner as to allow regions for material to spread horizontally instead of just accumulating vertically, based on the level of targeting optimization, and thereby allowing ~~self-correction~~ ~~self correction~~ of Z-accumulation. One such embodiment might involve the forming the object as a combination alternating solid layers and checkerboard ~~checker board~~ layers. Other such embodiments might involve the formation of solid outward facing surfaces and checkerboard, offset checkerboard, or other open structures in internal object regions. Other appropriate building patterns can be determined empirically by building and analyzing test parts.--

Paragraph beginning at line 28 of page 38 has been amended as follows:

--Some offset surface targeting embodiments might be used to simultaneously form different portions of objects and/or supports such that their upper surfaces are intentionally at different heights after formation of any given layer. These different height embodiments might benefit from utilization of data manipulation techniques, like the SMLC techniques, discussed in previously referenced U.S. Patent No. 5,999,184 ~~Patent Application No. 08/428,951~~ as well as some of the ~~of the~~ other previously referenced U.S. Patents and applications.--

Paragraph beginning at line 4 of page 39 has been amended as follows:

In addition to the above noted time of flight issues, other issues arise that can be corrected using modified time of flight correction factors. For example, when using ID overprinting techniques to cause more build up, features on scan lines which are scanned in opposite directions will lose alignment since the feature will be extended in one direction on one line and

in the other direction on another line. This situation is depicted in Figures 17a and 17b. Figure 17a depicts two points 60 and 100 belonging respectively to scan lines traversed in directions 64 and 104. Regions 62 and 102 depict the extents of ~~extends of~~ deposited material associated with points 60 and 100, respectively. Figure 17b depicts the same points 60 and 100 where jetting occurs using four times overprinting (i.e. four droplet depositions per pixel). Extents of deposition are depicted with numerals 76 and 106 respectively. As can be seen, due to the different directions of overprinting, registration between the physical features on the two lines is lost. The above mis-registration can be corrected by an additional time of flight correction factor which can be empirically, or possibly theoretically determined so as to cause realignment of features on different scan lines. Of course this form of correction does not account for any extra length added to object features along the scanning lines.

Paragraph beginning at line 20 of page 39 has been amended as follows:

A different form of correction that can avoid both problems is proposed which involves recognition that a given pixel is not bounded on its far side, in the scanning direction, by an adjacent pixel that also calls for material deposition. Based on this recognition, no overprinting is used on such an unbounded pixel. As another alternative, the extra line length might be compensated for by using a form of drop width compensation similar to line width compensation used in photo-based stereolithography and as described in the previously referenced U.S. Patent ~~Application Nos. 08/475,730 and 08/480,670~~ Nos. 5,854,748 and 5,870,307 but applied only to the points along each scan line representing a transition from deposition to no deposition. As an approximate correction these "terminal points" could simply be deleted from the deposition pattern as they will be in the range of 1/2 to fully covered by the use of ID overprinting of immediately adjacent pixels. Another variant involves the use of shifted time of flight correction data to implement subpixelling ~~subpixeling~~ deposition.--

Paragraph beginning at line 10 of page 40 has been amended as follows:

In some situations it may be desirable to modify the object data by performing droplet width compensation (i.e. deposition width compensation). Compensation (by offsetting inward toward solid one or more full pixel widths) can be used to achieve enhanced accuracy if the drop width is at least somewhat greater than the pixel width and/or length. This technique may be used in combination with any of the embodiments described above or any embodiments

described herein after. As the drop width approaches or exceeds twice the pixel width (and/or length) better and better accuracy can be obtained by a single or multiple pixel offset. Droplet width compensation may be based on techniques like those disclosed in U.S. Patent ~~Application~~ Nos. ~~08/475,730 and 08/480,670~~ 5,854,748 and 5,870,307. Alternatively they may involve pixel based erosion routines. In some embodiments the pixel based erosions might involve multiple passes through a bit map wherein "solid" pixels meeting certain criteria would be converted to "hollow" pixels.

Paragraph beginning at line 22 of page 40 has been amended as follows:

--Some embodiment might involve the following steps wherein each edge of the bit map is: 1) In a first pass through the bit map all "solid" pixels which are bounded on their right side by a "hollow" pixel are converted to "hollow" pixels; 2) In a second pass all "solid" pixels which are bounded on their left side by a "hollow" pixel are converted to "hollow" pixels; 3) In a third pass all "solid" pixels which are bounded on their upper side by a "hollow" pixel are converted to "hollow" pixels; and 4) In a fourth pass all "solid" pixels which are bounded on their lower side by a "hollow" pixel are converted to "hollow" pixels. Other embodiments might change the order of steps (1) to (4). If more than a one pixel erosion is required, steps (1) to (4) can be repeated as multiple times until the correct amount of reduction is achieved. These embodiments can perform a reasonable droplet width compensation; however, they suffer from the short coming that pixels in solid corner regions (whether an object corner or an object edge that ~~doesn't run~~ does not run parallel to either the X or Y axis) are removed at a faster rate than pixels in which represent boundary regions that are parallel to either the X or Y axis.

Paragraph beginning at line 28 of page 41 has been amended as follows:

In situations where X and Y pixels dimensions are significantly different, droplet width compensation may only be necessary along one axis instead of both axes. In these situations, embodiments similar to those described above may be used wherein only a portion ~~the a portion~~ of the steps will be performed per erosion. It is anticipated that deposition width compensating schemes can also be utilized using subpixel offset amounts in either one or both of the X and Y dimensions.

Paragraph beginning at line 5 of page 42 has been amended as follows:

A technique (method and apparatus) known as randomization can be employed in the build process. This technique may be used in combination with any of the embodiments described above or any embodiments described herein after. According to this technique, the manner of dispensing material at each location for two consecutive cross-sections is varied. This can lead to a more uniform build up of material across a layer (i.e. lamina) resulting in the ability to potentially use thicker layers, thus improving build time. This technique also minimizes the

effects from any single jet or plurality of jets that may not be properly firing. The varying of deposition can occur in several ways. For example variation may occur by: 1) varying the jet which deposits material onto a given portion of a layer relative to the jet that deposited material on the corresponding portion of the immediately preceding layer; 2) varying the temporal order or spatial order of dispensing onto any given portion of the layer relative to any other portion of the layer; and 3) a combination of these, such as varying the main scanning orientation or direction and/or varying the secondary scanning orientation or direction. The varying of deposition from layer to layer can occur in a totally random manner or it can occur in a periodic or planned manner. A similar technique has been used in photo-based stereolithography though for a completely different purpose (see Alternate Sequencing in previously referenced U.S. <u>Patent No. 5,711,911</u> ~~Patent Application No. 08/473,834~~).

Paragraph beginning at line 9 of page 44 has been amended as follows:

Additional embodiments are depicted in Figures 10a and 10b, wherein the direction of scanning along corresponding scan lines is reversed between <u>two subsequent</u> ~~two subsquent~~ layers. Figure 10a depicts the scanning directions for scan lines on a first layer wherein scan lines $R_5(1)$ and $R_5(3)$ are scanned from left to right and scan line $R_5(2)$ is scanned from right to left. Figure 10b depicts that the scanning directions are reversed on a subsequent layer wherein scan lines $R_6(1)$, $R_6(2)$, and $R_6(3)$ overlay $R_5(1)$, $R_5(2)$, and $R_5(3)$, respectfully, and wherein scan lines $R_6(1)$ and $R_6(3)$ are scanned from right to left and scan line $R_6(2)$ is scanned from left to right.

Paragraph beginning at line 11 of page 45 has been amended as follows:

In some embodiments, offsetting of pixels and therefore drop sites might occur during support structure formation to enhance the formation of arch-like supports, bridges, or branching supports (e.g. like limbs of a tree). In some embodiments, offsetting of pixels might occur during object formation to enhance building of object sections which protrude a limited amount beyond the boundaries of the immediately preceding object lamina. Protruding supports and object portions can be formed without the use of offset <u>pixelling but it is believed that offset pixelling</u> ~~pixeling but it is believed that offset pixeling~~ can be useful to aid in the formation of such structures wherein less material may slump into regions below the layers levels at which it was dispensed.

Paragraph beginning at line 2 of page 47 has been amended as follows:

Interlacing is another technique that can be used to enhance object formation. As with all other embodiments disclosed herein, the embodiments of this section are combinable with the other ~~with the those other~~ embodiments disclosed herein. As discussed previously, if the head is not oriented at the saber angle, the spacing between the jets is not equal to the desired resolution and thus is not equal to the desired spacing of main scanning or raster lines. As such, by its nature, a form of main scan line interlacing must be used if it is truly desired to deposit material along all main scan lines. However, additional interlacing may be done for a number of reasons (e.g. to enhance layer cooling and/or material build up).

Paragraph beginning at line 22 of page 50 has been amended as follows:

In these interlacing techniques, successive scan lines may be exposed using different or shifted interlacing patterns so that two dimensional interlacing patterns may be developed (offset pixelling could also be used). For example, a two step interlacing pattern may be used on each scan line wherein the starting points on successive lines are shifted by one pixel such that a checkerboard first pass pattern is formed. Figures 13a and 13b illustrate this example. Figure 13a depicts the first pass checkerboard pattern while Figure 13b depicts the complementary ~~checkboard~~ checkerboard pattern that is exposed on a second pass.

Paragraph beginning at line 5 of page 51 has been amended as follows:

A third interlacing technique involves feature sensitive interlacing. In this technique the order in which a given drop site is exposed depends on the geometry of the immediate cross-section alone or on multiple cross-section geometries. Feature sensitive interlacing may involve one or both of scan line interlacing and drop location interlacing. For example, in a single layer embodiment one may determine the boundary regions of the cross-sections and ensure that the boundary zones are exposed on a first pass. Some interior portions of the cross-section might also be exposed on the first pass or alternatively exposure of all interior portions may be delayed until one or more subsequent passes are made. For example, the interior portions may be exposed using a ~~checkboard~~ checkerboard interlacing pattern on a first pass in combination with all boundary regions also being exposed on the first pass. Then on a second pass the remaining interior portions would be exposed. It is also possible that a wide boundary width could be

defined for exposure on a first pass so that more than a one-drop site ~~one drop site~~ width border may be placed around the cross-section prior to performing subsequent passes. This wide boundary region might be implemented using erosion routines such as those described above in association with Droplet Width Compensation. As an additional alternative, one may focus on ensuring that only one of scan line boundary sites or drop location boundary sites (boundaries along lines in the secondary scanning direction) are exposed on the first pass. As a further alternative, internal regions may be exposed in whole or in part prior to dispensing material in boundary regions. It is believed that dispensing boundary regions first might lead to improved build-up in the vertical direction and that exposing boundary regions last might lead to improved horizontal accuracy of the object. An even further alternative might involve the dispensing of a near boundary region initially, followed by the dispensing of deeper internal regions of the cross-section and finally followed by dispensing of the outer cross-sectional boundary itself.

Paragraph beginning at line 20 of page 52 has been amended as follows:

In another preferred embodiment, the drop locations would be shifted by a fraction of a pixel width (preferably approximately 1/2 a pixel width) along the main and/or secondary scanning directions (preferably both) when dispensing unsupported down-facing regions and preferably adjacent regions such that a droplet is more likely to be at least partially supported by previously dispensed material than if droplets were deposited in perfect alignment. It is preferred that droplets over partially unsupported regions be dispensed in a subsequent pass from those dispensed over fully supported regions. However, it is possible to rely solely on the overlap with the previous cross-section (and not any additional benefit associated with adhesion to material previously dispensed on the given cross-section) in ensuring reasonable vertical placement of the droplets in partially ~~in at partially~~ unsupported regions. In this embodiment at least the support regions (e.g. columns) on the current layer would not be shifted. This ensures that registration from layer to layer occurs. It is further preferred that wide gaps be closed by progressively working deposition locations inward (i.e. multistage) from supported sides of the gap using multiple passes over the cross-section, wherein each pass is partially offset from the immediately preceding pass to ensure adequate overlap of droplets so as to limit any material placement beyond the required vertical level. Further, in one preferred embodiment, Simultaneous Multiple Layer Curing Techniques, as described in U.S. Patent No. 5,999,184 ~~Patent Application No.~~

~~08/428,951~~, are used in order to offset critical down-facing data up one or more layers so that upon deposition material forming the down-facing layer will be located at the correct level.

Paragraph beginning at line 12 of page 54 has been amended as follows:

In other preferred embodiments various aspects to the above example could be changed. For example, the extension of material into lower layer regions (assumed to occur when droplets or drop locations are only partially supported) could take on values other than the 1 layer thickness extension described. The extension may be less than 1 layer thickness or at least different from an integral number of layer thickness. Maybe the extension would be an integral number of layer thicknesses (e.g. 2 to 5 layer thickness or more). In such a case, for most accurate formation, it would be desired to have the initial object representation transformed into a modified representation, as described in U.S. Patent No. 5,999,184 ~~Patent Application No. 08/428,951~~, (either before or after generation of cross-sectional data) so that when material is dispensed according to the modified representation, the bottom of the down-facing feature is properly located. Other variations might use geometry based deposition, in multiple passes, along with different offset values such as 1/4 of a pixel (so that 3/4 of the drop zone would be unsupported) or 3/4 of a pixel (such that only 1/4 of the drop location would be unsupported). These different offset amounts might lead to more control over the amounts of extension into previous layer regions. Other variations might use different deposition orders, different amounts of over printing, or even quantities of deposition per droplet. Still other variations might not use offset ~~pixeling~~ pixelling but instead would use higher resolution pixels, possibly in combination with deposition patterns yielding the right droplet density.

Paragraph beginning at line 30 of page 54 has been amended as follows:

An additional interlacing technique combines: 1) feature sensitivity, and 2) selective direction of scanning when exposing object features. In this embodiment, cross-sectional geometry (e.g. cross-sectional boundary information) from a current layer and possibly cross-sectional geometry (e.g. cross-sectional boundary information) from the immediately preceding ~~preceeding~~ layer would be used to determine what the direction of scanning should be when exposing different regions of the cross-section. For example, when exposing the left most portion of a solid region of a cross-section it may be advantageous to be scanning the head (i.e. the jet used for exposing the line to be formed) from left to right if it is desired that the droplet not bridge or not partially bridge any small gaps. On the other hand, if it is desired that some bridging occur it may be ~~advantagous~~ advantageous to ensure that scanning is in the opposite direction. Similarly, when exposing the right most portion of a solid region of the cross-section it may be advantageous to be scanning from right to left (for no bridging) or from left to right (for bridging). By controlling the scanning direction when depositing boundary regions it can be ensured that horizontal momentum of the droplets either do not contribute to bridging gaps or enhance the bridging of gaps.

Paragraph beginning at line 30 of page 55 has been amended as follows:

It is anticipated that the object could be relatively ~~reorientated~~ reoriented (e.g. one or more rotations about the vertical axis) with respect to the relative scanning direction of the print head (i.e. jets) so that the edges of any desired cross-sectional features can be exposed while relatively moving the print head in a desired direction to enhance or decrease the probability of bridging small gaps.

Paragraph beginning at line 5 of page 56 has been amended as follows:

As noted above, if the orifice plate to working surface distance is too small, droplets will have an elongated shape (i.e. large aspect ratio) as they strike the working surface. In the case of building with elongated droplets, it is anticipated that the above indicated scanning directions for depositing on edges of solid features might yield opposite results from those indicated above. Other interlacing techniques might involve ~~bidirectional~~ bi-directional printing of adjacent raster lines or non-adjacent raster lines.

Paragraph beginning at line 11 of page 56 has been amended as follows:

The above-described ~~above described~~ building techniques can be applied to the formation of solid objects or in combination with other techniques to the formation of partially hollow or semi-solid objects. In an original design of an object, portions of the object are supposed to be solid (i.e. be formed of solidified material) and portions are supposed to be hollow (i.e. empty regions). In actuality these intended hollow (or void) regions that are not supposed to be part of the object, since by definition wherever there is object there is supposed to be material. In the context of the present invention a non-solid, hollow, or semi-solid object, is an object built or to be built according to the teachings of some preferred embodiments wherein a portion of what should be solid object has been removed. A typical example of this might be the hollowing out, partial hollowing out, or the honeycombing of what was originally a solid structure of the object. These originally solid structures are sometimes referred to as object walls regardless of their spatial orientation. Some preferred build styles form completely solid objects, while other build styles form solid surface regions of the objects but have hollowed ~~but hollowed~~ out or partially hollowed out interior regions. For example, the interior portions of an object might be formed in a ~~checkboard~~ checkerboard, cross-hatched, hexagonal, tiled, or honeycombed manner (these and other build styles useful herein, as implemented in photo-based stereolithography are described in the above referenced patents and applications). The above non-solid deposition patterns can be considered internal object support structures. As such the other support structures described herein can also be used as internal object support structures. Such non-solid objects would be lighter in weight than their solid counterparts, they would use less material, they might even be formed more quickly depending on the details of the specific building parameters, and they might be formed with less risk of encountering heat dissipation problems since much less heated material is deposited during their formation. These objects might be useful as investment casting patterns due to the decrease in the possibility of cracking molds.

Paragraph beginning at line 17 of page 59 has been amended as follows:

On the other hand, as noted above, curl and other distortions can be significantly reduced by building at elevated temperatures wherein the higher the temperature the less the distortion. It is postulated that this reduction in distortion results from a combination of the ~~material's enhanced ability~~ enhanced ability of the material to flow at elevated temperatures and its lower ability to support shear loads which allow some material redistribution to occur thereby reducing stress which causes distortion. It is further postulated that working near, at, or preferably above any solid state phase change temperatures (e.g. crystallization temperature or glass transition

temperature) will result in the quickest and potentially most significant reductions in stress and distortion. Since these phase changes typically occur over a broad range, various levels of benefit are postulated to occur depending on where the working temperature is in within these ranges and the process time allowed. Melting temperatures and/or solidification temperatures and solid state transition temperatures can be determined using Differential Scanning Calorimetry (DSC) techniques which in turn can be utilized in determining appropriate build temperature ranges. Additionally, appropriate build temperature ranges can be determined empirically. It has been determined that some benefit can be gained by working at any temperature above room temperature and it is anticipated that the closer one moves to the melting temperature and/or solidification temperature the more the benefit. Thus, the working temperature range might be set as a percentage of the distance along the temperature differential between room temperature and melting or solidification temperature or room temperature and the temperature of estimated minimum shear strength. Alternatively, the working temperature may be selected to be a temperature for which the material has a certain percentage of its room temperature shear strength. For example it might be desired to set the working (build) temperature such that the shear strength is 75%, 50%, 25% or even 10% of its maximum room temperature value.

Paragraph beginning at line 21 of page 61 has been amended as follows:

Figure 25c depicts the preferred orientation (~~rightside~~ right side up) of portion 62 during formation so that surfaces 50, 52 and 54 are formed as up-facing features. Figure 25d depicts the preferred orientation (upside down) of portion 64 during formation so that surfaces 56 and 58 are formed as up-facing features. After formation of each portion 62 and 64 the supports are removed and temporary pairs of surfaces 72 & 72', and 74 & 74' are prepared for mating. Figure 25e depicts the joining of portions 62 and 64 to form object 60 wherein all critical outward facing portions (i.e. original surfaces 50, 52, 54, 56 and 58) have good surface finish.

Paragraph beginning at line 17 of page 62 has been amended as follows:

Support structures must serve several needs which may be opposing: 1) they preferably form a good working surface on which to build object lamina and even successive support lamina; 2) they are preferably easily removable from the down-facing surfaces they support; 3) if they start from an up-facing surface of the object, they are preferably easily removable therefrom; 4) when removed, ~~the suports~~ the supports preferably cause only minimal damage to

down-facing and up-facing surfaces and preferably have at least a tolerable to good surface finish on those surfaces; 5) they preferably build up at a reasonable rate per cross-section in the vertical direction (e.g. Z-direction); 6) they are preferably formed using a minimal number of passes per layer; and 7) their formation is preferably reliable. A number of different support styles have been developed or proposed which achieve different balances between these needs.

Paragraph beginning at line 13 of page 63 has been amended as follows:

Some preferred support style embodiments emphasize speed of formation, maintain easy removal, but leave rough surface finish in regions where supports have been removed. ~~These support~~ This support style involves the formation of solid columns which are separated by small gaps. In particular, in a preferred system, data is supplied at 300 pixels per inch in both the X and Y directions and the object and supports are formed using four times ID overprinting in the X direction (main scanning direction). Each layer of supports includes three-by-three pixels zones where support material is to be dispensed with the columns separated by two pixels zones of no pixel defined deposition along the main scanning direction (X-direction) and one pixel zone of no pixel defined deposition in the secondary scanning direction (Y-direction). The data situation defining these pixel zones is depicted in Figure 15a. The "X's" in the figure depict pixels which contain droplet data while the "O's" in the figure depict pixels which contain "no droplet" data. Squares 50 have been inscribed around the "X" zones so as to highlight the shape of the deposition zones. However, due to the ID overprinting in the X-direction, the two pixel gaps are actually narrowed considerably (by almost one pixel width) when actual deposition occurs. Thus, the actual resulting pattern of deposition more closely approximates 4 by 3 pixel width (12-14 mils by 9-10 mils) columns, though with rounded corners, which are separated by 1 pixel width gap in both X and Y (3.3 mils). This situation is approximately depicted in Figure 18.

Paragraph beginning at line 10 of page 66 has been amended as follows:

Figure 29b depicts a first branching in the X direction. As with the other Figures to follow, the hatched solid regions, as depicted, represent the deposition regions for the instant cross-section whereas the region(s) depicted with dashed lines represent the immediately proceeding branch. This way of depicting the deposition regions is done to make the registration between branches clear. This first branching may occur after one or more trunk layers are formed. As with other branches to be described herein after in association with this figure and

other figures to follow, branching may extend the dispensed material out from supported regions by a fraction of a pixel, a full pixel, or multiple pixels depending on the drawing order used, the pixel width as compared to the drop width, the number of identical layers to be formed above the present layer (which can compensate for imperfections in the present layer), ability of the material to be partially unsupported, and the like. As with some of the other branches, to be discussed herein after, this branching can be looked at as a two way branch (i.e. one way in the positive X direction and the other way in the negative X-direction) or as a one-way branch of two or more initially overlapped components. As will be seen from the description to follow, this first branch may be considered a one-way branching of four initial components wherein two components follow each branching direction. The actual deposition of material from these four components may be based on a Boolean union of the components so that multiple depositions over overlapping regions ~~is avoided~~ are avoided.

Paragraph beginning at line 28 of page 69 has been amended as follows:

It has been found useful to include periodic bridging elements between the support columns to limit their ability to shift from their desired XY positions as they grow in height. Typically the smaller the diameter of the support columns the more often bridging elements or layers are needed. These bridging elements may extend one or more layers in height. In the preferred embodiment, it has been found that a single layer (1-2 mils) of bridging elements is not completely effective and that more than five layers (5-10 mils) makes the overall support structure too rigid. Thus, when using the preferred 3 by 3 pixel supports, bridging layers ~~are preferrably~~ are preferably between 2 layers (2-4 mils) and 5 layers (5-10 mils) in height and ~~most preferrably~~ most preferably 3 layers (3-6 mils) in height. Furthermore, it has been found that the bridging layers are preferably ~~are preferrably~~ repeated every 75 mils to 2 inches, ~~more preferrably~~ more preferably every 100 to 300 mils, and most preferably every 100 to 200 mils. For use with other materials, building parameters, or building conditions, formation and analysis of test parts can be used to determine the effective bridge thickness and separations thicknesses.

Paragraph beginning at line 7 of page 70 has been amended as follows:

When bridging layers are periodically used they may bind all support columns together or they may bind only a portion of them together wherein the other columns were bound on a previous use of bridging or will be bound on a subsequent use of bridging. In other words, the

bridging elements may form a solid plane of deposited material or alternatively they may form only a partially solid plane (e.g. a ~~checkboard pattern~~ checkerboard pattern) which connects some of the columns together. The support columns may or may not be shifted from their previous XY positions when they are restarted after formation of bridging layers.

Paragraph beginning at line 14 of page 70 has been amended as follows:

Another preferred support structure which emphasizes easy removal and good down-facing surface finish over speed of object production is known as a ~~checkboard support~~ checkerboard support. The cross-sectional configuration of this support structure is depicted in Figure 14. Along each raster line, deposition occurs using every other pixel (300 pixels/inch) and in adjacent raster lines the deposition pixels are shifted along the line by one pixel width. One preferred version of this support does not use ID overprinting, but can use DD overprinting or multiple exposures to increase deposition per layer. Without DD overprinting or multiple exposures, the layer thickness when using this type of support in the preferred embodiment is limited to under 0.4 to 0.5 mils, instead of the approximately 1.3 mils obtainable with some preferred embodiments described previously. Instead of using DD overprinting or multiple exposures with these supports, it is possible to not use the preferred ID overprinting of the object, and simply deposit material in thinner layers (e.g. 0.3 to 0.5 mils per layer). Overprinting of the object does not need to be utilized as the extra material would simply need to be removed during the planarization ~~ste. Since~~ step. Since raster scanning is used and since the speed of forming a layer is the same with or without overprinting, build styles according to these techniques are approximately 3 to 4 times slower than equivalent build styles where four times overprinting are used. Though there is a significant increase in build time the improvement in surface finish may warrant its use under certain circumstances.

Paragraph beginning at line 14 of page 71 has been amended as follows:

Another possible support style involves the use of solid or periodically broken lines which are preferably less than 3 pixels wide (less than 10 mils) and more preferably 1 to 2 pixels or less in width (less than 3.3 to 6.6 mils) and are separated by 1 to 2 pixels or less of undeposited material (less than 3.3 to 6.6 mils). These supports may run along the [the] main scanning directions, secondary scanning directions, or other directions. Another type of support is curved line supports which follow the boundary of an object. Alternatively, the support pattern can differ at different areas of the cross-section. It can also be displaced from the

boundary of the object by N pixels (or drop widths) in the scan direction, or M pixels (or drop widths) in the index direction.

Paragraph beginning at line 26 of page 71 has been amended as follows:

Further types of support structures useful for Selective Deposition Modeling are Hybrid Supports. In its simplest sense, a ~~hybird~~ hybrid support is a support structure that includes at least two different types of support structures. Preferably, the structures used in a hybrid support vary depending on the height of the support and, more particularly, the structure at any given point may depend on the distance from that point to an up-facing and/or down-facing surface of the object. In other words, the support structures are tailored to the most appropriate structure based on the distance to the object. In an exemplary embodiment, the support pattern is changed when the point is located a predetermined number of layers (e.g., 4 to 9) below a down-facing surface. In another, the drop density per unit area or drop density ratio (defined as the drops to non-drops per unit area ratio) of the supports is decreased as a down-facing surface is approached. In a variant of these embodiments, one or more layers of shelving (or intermediate) layers are used when transitioning from higher to lower drop density ratio support structures.

Paragraph beginning at line 22 of page 73 has been amended as follows:

~~Preferrably~~ Preferrably, if used, these intermediate layers are of similar thickness to that of the previously discussed bridging layers.